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TRADE AND DEVELOPMENT ASPECTS AND IMPLICATIONS OF NEW AND EMERGING TECHNOLOGIES:

THE CASE OF BIOTECHNOLOGY

Report by the UNCTAD secretariat

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CONTENTS

	Paragraphs
Summary and conclusions	(i)-(xi)
Chapter I: The potential of biotechnology in agriculture	1-19
A. Introduction	1-4
B. Biotechnology in agricultural applications	5-14
C. Incidence on developing countries' agricultural trade	15-19
Chapter II: The privatization of research in biotechnology	20-40
A. The dynamics of agricultural R & D and industry structure	20-28
B. Intellectual property rights protection in biotechnology	29-37
C. Implications for developing countries	38-40
Chapter III: Direction of research and the capabilities of developing countries	41-57
A. Research pathways in the developed countries	41-46
B. The status of research in and for developing countries	47-57

Summary and conclusions

(i) The new biotechnologies -- chiefly plant tissue and cell culture and the transfer of genetic material between plants -- are greatly expanding the tools available for crop improvement. Plant breeding research aims at increasing yields of cultivated plants and the nutritional value of crops, selecting varieties with resistance to disease and pests, and creating new varieties adapted to particular soils and climatic conditions or possessing other desired characteristics. The techniques traditionally employed to achieve these aims have entailed the creation of new genetic structures in plants through successive cross-breeding with selected varieties based on normal plant reproduction processes. Plant tissue and cell culture techniques, the most developed of the new biotechnologies, can, among other things, increase the efficiency and effectiveness of plant breeding by permitting the reproduction of plants on a massive scale and in a far shorter time span than is possible with ordinary cross-breeding, thereby speeding up the identification and propagation of superior varieties. The transfer of genetic material from one living cell to a plant cell of another species through recombinant DNA and cell fusion techniques permits the introduction of entirely new and improved characteristics to the receiving plant and its offspring, outside of normal reproductive processes.

(ii) Biotechnology can be potentially applied to breeding programmes for a wide range of crops accounting for a substantial value of agricultural production and trade of developing countries. The stakes for developing countries are potentially quite large, even though the present technical bottlenecks in industrialized countries where most of the R & D is undertaken are such that the applications to most crops are not expected to become routine until well after the year 2000.

(iii) The actual as compared with the potential generation and diffusion of biotechnology and its applications depends on the complex interaction of an array of not only technical but also economic and institutional factors. Several of these factors are of a nature as to prompt possibly unfavourable forecasts with respect to the diffusion, transfer and application of biotechnologies to the improvement of crops cultivated in developing countries. The growing relative importance of private as compared with publicly-funded agricultural R & D is leading to an extension of the rule of secrecy and confidentiality with regard to the dissemination of knowledge in the field of biotechnology, however much it may stimulate enterprises to invest in R & D. The increasing tendency of even public institutions and universities to patent the results of their research is a further manifestation of the trend towards secrecy which could slow down or make more costly the dissemination of knowledge relevant to developing countries. Moreover, in so far as they do not participate in the emerging networks of manufacturers, research labs and public institutions engaged in the development of biotechnological innovations in industrialized countries, the developing countries are missing out in the generation and sharing of knowledge relevant to their needs and in the negotiation of licences under favourable terms that takes place among the participants. The "privatization" of the knowledge produced by biotechnological research contrasts with the openness and incitement to widespread dissemination of the results of largely publicly-funded Green Revolution research that contributed so much to agricultural productivity in many developing countries.

(iv) The drive to extend the scope of intellectual property rights protection of biotechnology through reform of industrial patent and/or plant breeders' rights legislation could accentuate these tendencies, particularly if it leads to a proscription of the existing right of breeders to use protected plant varieties for the creation and commercialization of new varieties.

(v) Unlike chemical or mechanical engineering, advances in agriculture are not readily transplanted from one locale to another without considerable investment in adaptation. This is because, although many of the crops grown in both developed and developing countries are the same, the research objectives (type of pest or of environmental stress) being targeted differ. However, except for a handful of major tropical exports, the private sector in developed market-economy countries has little commercial incentive to invest in the adaptation and transfer of biotechnology innovations to agriculture in developing countries. Hence, the ability of most developing countries to realize the potential offered by biotechnology for their agricultural production and exports will depend in part on the size and quality of their investment in adaptive R & D.

(vi) Fortunately, the expected delay before most of the projected applications in biotechnology will produce commercial results in agriculture makes it appropriate to consider a few of the possible options that can be exercized by developing countries and by the international community on their behalf in making the most of the opportunities that still exist.

(vii) With respect to national action, no more than a handful of the most technologically advanced developing countries have the alternative of being able to work at the frontiers of knowledge using genetic engineering to manipulate germplasm for the development of major improvements in their crops. Among remaining developing countries, those possessing at least a nucleus of qualified researchers in plant biotechnology will be in a position to exploit tissue culture methods and other simple techniques to modify and adapt innovations originating from developed countries to their own conditions of cultivation. For most developing countries, a high priority will be attached to building up an endogenous capacity in agricultural research through which external knowledge can be integrated. In a number of countries, particularly in Africa, this will mean a concentration of investment on as yet nascent or non-existent infrastructures associated with conventional plant improvement activities, conservation of genetic resources, programmes of plant selection and of production, distribution and quality control of seeds. More international support will be needed to expand plant breeding capacity together with research on local pests and diseases.

(viii) A major challenge facing developing-country Governments and the international community will be how to devise channels and mechanisms for the transfer of useful biotechnologies from private enterprises in developed market economies to developing countries and for the meaningful involvement of these countries in the research networks in biotechnology involving these enterprises that are being formed in the developed market-economy countries. It has been suggested in some quarters that new funding schemes be created to promote this interaction and that the International Agricultural Research Centres (associated with conventional breeding programmes) be given, as part of the intensification of their work on biotechnology, the function of

assisting developing countries to negotiate transfers of technology with private enterprises.1/

(ix) Special attention will need to be given to the promotion of research on a range of crops important to developing countries but not grown in developed countries -- including a number of widely consumed cereals, pulses and other food crops as well as some export crops -- in which the private sector in developed market-economy countries has no commercial interest.

(x) The question of intellectual property rights protection of living matter is a controversial topic whose implications for the creation and dissemination of innovations in biotechnology are not well understood. There is a need to study more carefully how different types of reform would achieve the aim of stimulating invention and promoting technology transfer and co-operation in the area of biotechnology, particularly with developing countries, before agreement is reached on the adoption of uniform international standards of protection of living material. A related issue meriting study is the corresponding protection of the traditional crop breeding by farmers in developing countries that has never been remunerated as such and which could serve as a means of conserving plant genetic resources. Moreover, since the International Agricultural Research Centres and other publicly-funded research organizations are encountering increasing difficulties in gaining access to privately controlled genetic material due to the growing use of intellectual property rights protection, it may be advisable for them to consider adopting proprietary protection for their own innovations in order to be able to assure the access to them of reseachers and plant breeders in developing countries.

(xi) The application of biotechnological innovations to agriculture offers a great opportunity to expand the food production base of developing countries without compromising sustainability. It also offers an opportunity to improve appreciably their export earnings. The challenge for Governments is to mobilize the international co-operation that is required in order to seize these opportunities.

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Chapter I

THE POTENTIAL OF BIOTECHNOLOGY IN AGRICULTURE

A. Introduction

1. This report has been prepared pursuant to resolution 32 (VII) of the Committee on Transfer of Technology, which recommended that the secretariat continue to give increased and systematic attention to the trade and development opportunities of new and emerging technologies, such as microelectronics, new materials and biotechnology. It draws on research from a larger study on agricultural biotechnology being carried out jointly by UNCTAD and the United Nations Industrial Development Organization.

2. Biotechnology, defined broadly as the economic application of biological processes, is not a recent activity. For centuries, mankind has applied various biotechnological techniques in agriculture, food processing, brewing and medicine. More recently, biotechnology has been used to prepare antibiotics and vaccines. It is, however, the advances in the basic genetic sciences and biochemistry in the last 20 years that have transformed biotechnology into an interdisciplinary science-based, rapidly advancing technology, with a greatly increased range of potential applications. And it is "modern biotechnology" with its capacity to manipulate living plants and animals at the level of the cell or molecule as distinct from traditional breeding and fermentation techniques, that is considered in the present report.

3. The first successful attempts at genetic engineering in the 1970s were often accompanied by over-optimistic forecasts as to the pace of the development, commercialization and diffusion of biotechnology. The slow rate of product introduction in the following years and a greater understanding of the scientific and technical difficulties still to be overcome are leading to revised evaluations of potential applications and the likely time-frame for their development. Investment patterns and technical progress, up to now, suggest that, in the coming years, biotechnology developments will concentrate mainly on human health and (to a lesser extent) agriculture. Although agriculture, particularly plant agriculture, accounts for a smaller share of total R & D expenditure in biotechnology and of the number of biotechnologically-derived products on the market than human health, it is agriculture that is at the centre of the debate concerning the opportunities and challenges of biotechnology for developing countries. This is due to several reasons. Firstly, for many developing countries, agriculture remains the main source of GDP growth and foreign exchange earnings. Secondly, biotechnology is expected to have the largest production and trade impact in agriculture.[2/] Thirdly, it is through agriculture that developing countries are likely to make their entry into modern biotechnology. It is these reasons, plus UNCTAD's more general concern in monitoring how technology affects developing countries' commodity trade, that have prompted the present report.

4. The report describes the opportunities afforded by plant biotechnology and its potential impact on crops that are important in the exports and imports of developing countries. The potential impact and its timing depends in large part on the state of the art in developed countries where the advances have been taking place, which is the subject of chapter I. The actual effects will take place in the future and will depend on a large number of factors, especially those relating to the diffusion and transfer of the relevant commercial applications of agricultural biotechnology to developing

countries. This question is addressed in chapter II which deals with the tendency towards privatization of R & D in biotechnology and chapter III which deals with the direction of research on biotechnology and the research capabilities of developing countries. In the summary and conclusions, the report takes up a number of policy options.

B. Biotechnology in agricultural applications

5. Agricultural research on the improvement of crop production aims at increasing yields of cultivated plants and the nutritional value of crops, selecting varieties with resistance to two adverse conditions, disease and pests and creating new varieties adapted to particular soils and climatic conditions or possessing other desired characteristics. Traditionally, the techniques employed to achieve these objectives in a given plant have entailed the creation of a new genetic structure through successive cross-breeding with selected varieties based on normal plant reproduction processes. Plant breeding, which was carried out by farmers over the centuries based on trial and error, has with advances in plant genetics and plant physiology turned into specialized science-based activity in more recent years. The creation of new varieties by plant-breeders has been accompanied by innovations from the chemical industries such as fertilizers and pesticides. Hence, the performance of improved varieties has been the result of an interaction between genetic improvements and interventions in the plant's environment.

6. The new biotechnologies used in the manipulation of the plant's germplasm are expanding the tools available for crop improvement. A brief introduction to the main techniques and their present status would help to give a general picture of the possibilities offered by biotechnology in plant breeding. The techniques of biotechnology used in plant breeding fall into two main categories: (i) tissue and cell culture and (ii) transfer of genetic material.

1. Tissue and cell culture

7. In addition to reproduction by seeds (so-called sexual reproduction) a number of plants can also reproduce themselves asexually from a detached leaf, piece of root, shoot or stem. When this occurs, the new plants are genetically identical to their parents. All plants and animals grow by cell division. When a single cell divides, it produces an identical copy of itself, so that each new cell contains the same, identical set of genes. Similarly, the whole plant that grows from the cell inherits the same genes of the parent plant from which the cell was taken. These biological laws form the basis of the technique known as tissue culture -- that is, the growing of individual plant cells or tiny pieces of tissue in culture (an artificial medium containing nutrients and plant hormones) that nourishes and keeps them alive. The cells then multiply and, depending on their metabolism, produce many different substances. Tissue culture, considered to be the real basis of plant biotechnology, makes possible:

- The mass propagation of selected varieties by producing many identical copies or "clones" of plants. From each gram of starting tissue it has been in many instances possible to clone as many as a thousand plants. For crops on which the technique works, it permits the reproduction of plants on a more massive scale and far shorter time span than is conceivable by ordinary plant breeding techniques. It eliminates the genetic variability and randomness that

characterizes traditional cross-breeding. Once a high-yielding, disease-free or "elite" plant has been identified, the biotechnologist can multiply identical copies of it. The time needed for carrying out breeding experiments can be reduced from months or even years to a few days or weeks.[3/] The potential time saving in determining the presence and effects of desired genes would be particularly important for perennial trees which normally take decades to mature. The creation of clonally-propagated oilpalms in Malaysia represents one example of which there exist many others. Disease-resistant plants can be identified more rapidly, since large numbers of cells, rather than whole plants can be exposed to the disease or stress-producing agents in culture. This application is particularly important for asexually propagated crops such as potatoes and cassava and a number of legume species that are traditionally infected by viruses.

- The production of natural plant-derived substances by inducing their production from the plant's cell propagated in culture rather than from the harvested plant itself. This could permit the mass production of fragrances, flavours, dyes and other plant products, normally originating from remote parts of the world, in the laboratory under controlled conditions. Examples of substances that could eventually be produced in this way include vanilla flavouring found in vanilla orchid; cocoa butter from the cacao plant; capsaicin (a hot spicy substance) from chili pepper and saffron derived from crocuses.

- Preservation of germplasm. The germplasm of some plants which are difficult or clumsy to store as seeds can be preserved using tissue culture, which also offers the advantage that the germplasm will be disease-free. Tissue culture also facilitates the reproduction and preservation of rare or endangered plants.

2. Transfer of genetic material

8. The manipulation of genetic information, which is responsible for the growth, maintenance and reproduction of all living things, represents the newest and most revolutionary set of techniques falling under the general heading of biotechnology. Every reproducible cell of a plant or animal contains within it deoxyribonucleic acid or DNA, an extraordinary molecule which encodes this genetic information in its chemical structure. In theory, if one can identify what kind of instructions or characteristics a specific gene contains, one has the potential to manipulate inherited characteristics in any living thing. The transfer of genes, segments of DNA, from one living cell to another permits the introduction of desired new characteristics into the receiving cell outside of the normal reproductive practice of the plant or animal from which the cell is taken. Theoretically, it is possible to incorporate genes from any source plant, animal or human) into the plant cell. The grown-up plants whose genetic material has been changed are referred to as transgenic plants. The plant cell's thick cellulose wall is a barrier to gene transfer that must be overcome in order to introduce the foreign DNA. What is referred to as recombinant DNA technology or genetic engineering invclves the selection and introduction of a specific gene (segment of DNA) into a cell by first inserting it into the DNA of a small microbe that acts as a carrier. The transfer is accomplished by using the

gene-carrying microbe to infect the targeted plant cell.[4/] If the process succeeds, the characteristic encoded in the foreign gene will be manifested or expressed in the plant cell. Other methods for getting genes from one cell into another are also being developed. These entail either the fusion of the two cells by using electric shocks or chemicals to break down their surfaces or the use of "guns", osmotic pressure or other techniques for inserting whole fragments of DNA from one cell into another. Since they all involve the transfer of large fragments or whole intact strands of DNA to the cell, these techniques result in the random incorporation of many genes that express many different traits. This contrasts with more precise and deterministic recombinant DNA methods involving the isolation and incorporation into the plant cell of specific genes that express specific traits.

9. The story does not end with the creation of the new, transformed plant cell. In order for this effort to have an impact on production, it must be possible to clone the cell and reproduce and propagate on a large scale the whole transformed plant. Tissue and cell culture techniques described previously are therefore a necessary complement to gene transfer.

10. So far, about 20 to 30 transgenic plants have been constructed, including some of the major crops depicted in table 1. Recombinant DNA technology is most advanced in tomatoes, potatoes, tobacco and rapeseed. Successful regeneration from fused cells has been achieved for maize, millet, rice and tropical forest legumes. Examples of the kinds of achievements that have been obtained or are being sought, depending on the crop, include: resistance to herbicides, insect pests and viruses; salt, drought and cold tolerance; improvement of nutritional quality; and faster ripening.

3. Other applications of biotechnology

11. Two important activities in plant breeding that are benefitting from advances in biotechnology are the detection of plant diseases and the identification or "mapping" of genes.

12. Most organisms have immune systems that act as natural defences against infection from viruses, bacteria and parasites. Whenever an organism is infected, its immune system is stimulated to produce proteins known as antibodies that recognize and assist in the destruction of disease agents carried on the surfaces of invading pests. Utilizing this principle, scientists with the aid of cell fusion have been able to clone cells that produce single specific antibodies (monoclonal antibodies) which recognize disease agents associated with specific pests. Kits have been constructed permitting diagnosis of the disease by means of a simple colour reaction. Similarly, with the aid of recombinant DNA techniques, scientists have been able to construct DNA probes: short lengths of DNA whose chemical components are complementary to a part of the DNA contained in the cells of specific pests. Because of its complementarity the DNA probe latches on to the DNA of the pest being targeted, thereby permitting its detection. Rapid antibody or genetic tests are becoming available for the diagnosis of numerous plant diseases.

13. A new approach to the location of genes and to understanding their biochemical mechanisms of action is known as RFLP mapping.[5/] The technique uses special bacteria enzymes that recognize specific short

sequences of DNA associated with certain genetic traits and cut the DNA where these sites occur. The cloned fragments of DNA can be used as "markers" to analyze the results of genetic crosses and follow how traits are inherited by observing the distribution of markers in the organism's DNA. RFLP mapping promises to be valuable to plant breeders, especially in breeding for traits such as drought resistance which depend not on one but on several different genes.

4. Technical constraints

14. Important technical stumbling blocks remain to be overcome before the promise of biotechnology can be realized for a broad range of agricultural crops. Some of the most important are:

(a) Far more knowledge is needed of the nature of diseases that attack plants, of the interaction between plants and pests and of the genetics of disease resistance, yield, quality and resistance to various environmental stresses such as drought, salinity, wind, etc.

(b) Successful regeneration and mass multiplication of plants is still only a reality for a limited number of crops due to the lack of sufficient knowledge of the specific mechanisms for regenerating different varieties and species. Thus, for example, a number of broad-leafed plants[6/] which grow from the tips of shoots and roots and whose seedling plants tend to have two leaves, have been amenable to plant tissue culture methods of clonal propagation. However, the regeneration of grasses and grass-like crops[7/] lacking these characteristics, notably cereals, has not progressed as fast. Exceptions are rice and, more recently, maize, in which there has been some success at the experimental level. On the other hand, not all broad-leafed plants can be regenerated. Woody plants, especially trees, have been particularly intractable.

(c) Even where plants have been regenerated and cloned, they often fail to meet expectations in field-testing and, therefore, do not reach commercialized production.[8/] Moreover, clonally propagated crops have a very narrow genetic base which makes them more susceptible to disease than their counterparts bred conventionally from seeds.

(d) Commercial production of natural, plant-derived substances from the tissues and cells of plants propagated in culture has been held back by an incomplete understanding of the physiology of their synthesis by plant cells, low rate of synthesis in culture in most instances as compared with the whole plant and absence of techniques for production and recovery of the substances on a sufficiently large industrial scale to make them cost-competitive with the same substances produced from the whole plant.[9/]

(e) A major impediment to the commercial development of transgenic plants is that researchers have only been able to identify a small number of useful genes. Since a single plant may contain some 100,000 genes (humans have 300,000), the task of identifying DNA for transfer from one variety to another is a daunting one.[10/] It is made more difficult by the fact that: (i) not

all genes are associated with a specific, outwardly observable characteristic of the plant and that certain characteristics result from the interaction of not one but several genes;[11] and (ii) the timing and conditions under which genes express the characteristics they control varies from one type of gene to another. Finally, even after a research team has succeeded in identifying and (through the use of recombinant DNA or cell fusion methodologies) transferring a sought-after gene to the cell of a targeted plant variety, two important steps remain with their own sets of problems that have been described above. They are regeneration of the adult plant from the transformed cell and field-testing of the plant.

C. Incidence on developing countries' agricultural trade

15. The preceding discussion has shown that the extent of progress achieved in applying the various biotechnological techniques to agriculture is uneven and still rather short on actual results. Table 1 summarizes the information that the secretariat of UNCTAD, in collaboration with UNIDO, was able to piece together with the help of scientific experts and miscellaneous published sources on current views of the status of the main biotechnologies discussed in this report as they relate to individual traded commodities. It focuses on commodities that account for a substantial volume of developing countries' exports or imports. It is incomplete because it excludes a number of individual crops for which it was not possible to obtain information, either on the amount of trade on a sufficiently disaggregated level, or on the state of scientific progress to date. The table also gives an incomplete picture of the potential economic importance of the biotechnologies, because it excludes certain crops that are consumed domestically (such as teff in Ethiopia and quinoa in several Andean countries) but not internationally traded in commercially significant quantities.

16. Such as it is, the information nevertheless permits a number of observations to be made. Column 6 of table 1 underscores the very limited results that have been realized in the application of the most sensational of the new biotechnologies: genetic engineering. Inability of scientists to use this set of techniques routinely means that there are as yet no transgenic crops on the market. Some encouraging experimental results have been reported for maize, potatoes, tomatoes, rapeseed, tobacco and rubber -- suggesting the possibility of seeing genetically engineered versions of these crops on the market in as little as five years. Far more substantial progresss has been realized in the application of tissue and cell culture techniques. As depicted in column 5, the regeneration and clonal propagation of plants is now or soon will be practicable for a large number of economically important crops. In the case of cereals which have already benefitted considerably from conventional crop breeding research under the Green Revolution, tissue culture is being applied in conjunction with, as yet unsuccessful, attempts to genetically engineer new, improved varieties. Selected, superior varieties of clonally propagated cassava, potato, tomato, banana, tobacco and rubber crops are already being commercialized; and superior varieties of several other clonally propagated crops shown in the table may be on the market in five years time. In addition to the crops shown in the table, clonal propagation is reported to be at various stages of development for another 35 vegetables, trees and shrubs and ornamentals (flowers) for which global trade data are not

Table 1

Availability of new plant biotechnologies for selected agricultural commodities with corresponding value of trade of developing countries and territories (average 1985-1987)

Commodity [a]	*Exports to world (US$ mill.)*	*Imports from world (US$ mill.)*	*Availability of new technologies*				*Timeframe for transgenic plants (years)*
			Diagnostics	*RFLP markers*	*Tissue and cell culture*	*Transgenic plants*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Total (28 commodities) [b]	45,704	29,708					
Cereals							
Wheat	858	7,549	3	1	2	0	over 10
Rice	1,630	2,368	3	2	3	1	5 - 10
Maize	1,094	2,616	3	3	2	2	0 - 5
Barley	28	1.063	3	2	2	1	5 - 10
Sorghum	235	385	...	1	2	0	over 10
Millet	9	12	...	0	1	0	over 10
Triticale	0	0	...	1	2	0	over 10
Rye	0	8	...	0	2	1	5 - 10
Vegetables							
Cassava	684	29	3	1	3	1	5 - 10
Yams	13	1	...	1	2	1	5 - 10
Sweet potatoes	9	4	...	1	2	1	5 - 10
Potatoes	139	260	3	1	3	2	0 - 5
Tomatoes	384	99	...	1	3	2	0 - 5
Fruits							
Bananas/plantains	1,603	160	3	1	3	1	5 - 10
Pineapple	472	60	...	...	2	0	over 10

Table 1 (contd.)

Availability of new plant biotechnologies for selected agricultural commodities with corresponding value of trade of developing countries and territories (average 1985-1987)

Commodity [a]	*Exports to world (US$ mill.)*	*Imports from world (US$ mill.)*	*Availability of new technologies*				*Timeframe for transgenic plants (years)*
			Diagnostics	*RFLP markers*	*Tissue and cell culture*	*Transgenic plants*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sugar [c]	6,808	2,289					
Sugar cane	...	...	3	...	2	0	over 10
Sugar beet	...	...	2	...	2	1	5 - 10
Tropical beverages							
Coffee	11,613	1,019	3	...	3	0	over 10
Cocoa [d]	3,775	287	3	...	2	0	over 10
Tea	1,529	1,033	3	...	2	0	over 10
Spices							
Vanilla [e]	84	1	...	...	3	...	...
Vegetable oilseeds, oleaginous fruits [f]							
Soyabeans	3,688	3,491	2	2	...	1	5 - 10
	(660)	(1,215)					
Sunflower seeds	553	692	2	...	...	1	5 - 10
	(393)	(502)					
Rapeseed	35	493	2	...	2	2	5 - 10
	(18)	(410)					
Coconuts (copra)	871	161	...	...	1	0	over 10
	(539)	(88)					
Oil palm	2,350	1,589	...	...	2	0	over 10
	(2,249)	(1,588)					

Table 1 (contd.)

Availability of new plant biotechnologies for selected agricultural commodities with corresponding value of trade of developing countries and territories (average 1985-1987)

Commodity [a]	*Exports to world (US$ mill.)* (1)	*Imports from world (US$ mill.)* (2)	*Availability of new technologies*				*Timeframe for transgenic plants (years)* (7)
			Diagnostics (3)	*RFLP markers* (4)	*Tissue and cell culture* (5)	*Transgenic plants* (6)	
Raw materials							
Tobacco	1,726	809	2	...	3	2	0 - 5
Rubber	3,049	716	...	...	3	2	0 - 5
Cotton	2,465	2,514	...	...	1	1	5 - 10

Source: Trade: Food and Agriculture Organization, *Trade Yearbook* tapes;
Biotechnologies: UNCTAD secretariat estimates based on report prepared for UNCTAD and United Nations Industrial Development Organization by Professor D. Boulter, Dr. G. van den Eede and Professor M. van Montagu, 29 January 1990, Technical Centre for Agricultural and Rural Co-operation/Food and Agriculture Organization, *Symposium on Plant Biotechnologies for Developing Countries: Conclusions and Recommendations*, Luxembourg, 26-30 June 1989; Bureau Européen de Recherches S.A., "The impact of biotechnology on agriculture in the European Community to the year 2005," Brussels, November 1988.

a For precise coverage of commodity categories, see Annex table II.
b Sample accounts for approximately 66 and 54 per cent, respectively, of all developing-country/territory exports and imports of commodities of plant origin.
c Refers to raw and refined sugar; breakdown into cane and beet sugar not available.
d As stated in the text, serious problems remain to be overcome in producing cocoa butter directly in culture and even more problems in producing it economically. On the other hand, column (5) indicates that tissue culture has been used with some success in regeneration and clonal propagation of cacao plants.
e Column (5) refers primarily to the direct production of vanilla in culture which is close to becoming commercial.
f Figures in parentheses refer to trade in oils. The total figures include trade in seeds, fruits, oils and oilmeals.

Note: 0: technique not available; 1: many problems to be solved; 2: some success reported, but technique cannot yet be used routinely; 3: technique can be routinely used; ... : no information available

available. These include several -- ginger, garlic, taro, bamboo, eucalyptus and papaya -- that are of particular interest to developing countries.

17. Table 1 (column 5) shows only two major agricultural crops on which biotechnological research is aiming at the objective of producing plant substances directly in culture. Of these, it is only vanilla that is anywhere near commercial production. Research on tissue culture synthesis has been underway on a range of high-value substances -- raw pharmaceutical products, aromatic compounds, condiments and fragrances contained in crops that do not figure in global trade statistics, but which are of some importance in the exports of a few individual countries.12/ However, what little information is available suggests (for reasons already spelled out in this report) that commercial results from this research are still far off. The potential impact on developing-country exports from competing substances synthesized in culture could seem to be rather remote at the present time.13/

18. The complexity and unquantifiability of the many factors that determine trade in individual commodities do not make it feasible to come up with meaningful figures on the projected impact of advances in biotechnology that have been discussed in this report.14/ In lieu of such an estimate, an attempt has been made in table 2 to show the average value of exports in 1985-1987 of major crops and categories of crops that are likely to be affected by either tissue culture or genetic engineering, together with a very rough prediction of the timeframe in which the techniques are expected to produce commercial results. Thus, tissue and cell culture techniques could be expected to affect potentially a value of major agricultural exports amounting to approximately $42 billion within the next five to ten years; whereas the corresponding value for genetic engineering would be only $24 billion. As indicated by table 2, as well as by Annex Table 1, the number of developing countries for which potentially affected individual commodities account for at least five per cent of total trade is also quite significant. It is clear, therefore, that developing countries have an important stake in the future development of biotechnology and its agricultural applications.

19. It must be stressed that the estimates are for values of <u>potentially</u> affected exports. What is not necessarily clear from such estimates is whether the applications that are developed will be relevant to the needs of developing countries in all instances. Moreover, the ability of developing countries to benefit from biotechnological advances will depend on a number of factors. These issues are dealt with in the next two chapters.

Table 2

Timeframe of application of two main categories of biotechnologies to selected commodities and corresponding value of affected exports of developing countries and territories

A. Tissue and cell culture techniques

Timeframe for routine use [a]	*Value of exports (US$ billions)*	*Commodities* [b] *affected (no. of developing-country/territory exporters* [c]*)*
Up to 1995	20.9	Coffee (28), bananas/plantains (16), rice (6), rubber (5), tobacco (2), vanilla (2), cassava (1), potatoes (1)
1995-2000	21.2	Sugar cane/sugar beet (16), cocoa (15), tea (4), soyabeans (3), oil palm (3), wheat (3), maize (1), sunflower (1), pineapple (0), sorghum (0), barley (0), sweet potatoes (0), yams (0)
After 2000	3.4	Cotton (15), coconut (10), rapeseed (0), millet (0)

B. Transgenic plants

Timeframe for routine use [a]	*Value of exports (US$ billions)*	*Commodities* [b] *affected (no. of developing-country/territory exporters* [c]*)*
Up to 1995	6.4	Rubber (5), tobacco (2), maize (1), potatoes (1), tomatoes (0)
1995-2000	17.5 [d]	Sugar beet (16), cotton (15), bananas/plantains (16), rice (6), soyabeans (3), cassava (1), sunflower (1), barley (0), rapeseed (0), sweet potatoes (0), yams (0)
After 2000	21.7	Coffee (27), sugar cane (16), cocoa (15), coconut (10), tea (4), oil palm (3), wheat and flour (3), pineapple (0), sorghum (0), millet (0)

Source: Trade figures and sources used in assessment as in table 1.

a The timeframe for application of tissue and cell culture techniques is obtained from table 1 by making the following assumptions: Up to 1995: the techniques depicted in table 1 can be routinely used "3" (in column (5)); 1995-2000: the techniques depicted in table 1 are close to being routinely used "2" (in column (5)); after 2000: all other cases.

b For commodity categories, see annex table II.

c Includes countries for which share of exports in total exports is above 5 per cent, as in annex table I.

d Includes total value of sugar exports. Impact in this case would be in the form of substitution.

Chapter II

THE PRIVATIZATION OF RESEARCH IN BIOTECHNOLOGY

A. The dynamics of agricultural R & D and industry structure

20. Traditionally, agricultural research has been linked with public institutions. It was publicly-funded research that was largely responsible for the development of high-yielding varieties of seed grains associated with the Green Revolution. This contrasts markedly with the pharmaceutical and plant-protection industries in which for some time it has been the private sector that carries out almost all R & D. Today, the estimates of research budgets in plant biotechnology show a preponderance of the private over the public sector, the latter being responsible for only about 30 per cent of total research in the new biotechnologies.[15/] In part, this change in balance corresponds to a reduction in public funding of agricultural research that may be illustrated by the sale to Unilever of the Plant Breeding Institute in the United Kingdom. The tendency is downwards in all countries of the EEC, except France, stable in the United States of America and upwards in France. On the whole, the change in balance consists of a growing commitment on the part of private enterprises. It is due also to the transformation of the structure of the main branches of the agro-industry sector -- a transformation brought about by the new biotechnologies.

21. At the same time that developments in biotechnology have increased the private sector's role in agricultural R & D, they have been changing the way in which R & D is organized. Increasingly, research is being conducted on the basis of partnerships of varying duration involving a proliferating network of consultancy contracts, granting of licences, joint research programmes and joint ventures. The specific linkages between the public and private sectors are also quite diverse. Often, companies will establish commercial relationships with a number of different universities engaged in biotechnology-related research. In other instances, university scientists will figure prominently in the work of commercial biotechnology research laboratories or act as consultants or members of scientific advisory panels to industrial companies. This evolution is due to several factors. It is explained in part by the interdisciplinary nature of biotechnologies: to produce an innovation, it is often necessary to bring together various disciplines (molecular biology, cell biology, plant physiology, biochemistry, etc.) that are not necessarily to be found in the same industrial enterprise, laboratory or even in the same university. It is reinforced by the active participation of the users of the innovation in defining their requirements -- what market niche -- for a particular vegetable oil, under what cost constraints? It is also attributable to a blurring of the boundary between basic and applied research, as demonstrated by the frequency with which industrial researchers publish articles in scientific reviews and participate in symposiums, and the number of scientific articles quoted when a patent concerning genetic engineering is filed.

22. In this setting, the structure of the basic branches of agro-industry has been undergoing a transformation. At the centre of this transformation is the seed industry. The commercial interest in this industry is not immediately obvious since, in terms of cost, seeds occupy a marginal position in comparison to other inputs to agriculture. The proportionate contribution of seeds is roughly two-thirds of that of plant protection products and only

one-third of that of fertilizers. However, most analyses indicate that advances in genetics have been responsible historically for over 50 per cent of the gains in agricultural productivity.[16/] Taking into account their intrinsic contribution to agricultural value added, seeds today are undervalued. With the emergence of plant biotechnologies and improvement in the ability to exploit them, the years to come should bring an increase in the contribution of genetics to the seed industry and to the role of seeds in agriculture. Hence, the sustained interest of private capital in these new technologies. In light of the limited results achieved to date, this interest is explained more by the expected potential of biotechnology in the years to come than by the products and processes that have already come on the market.

23. The development of plant biotechnology is intertwined with several industrial sectors, each with its own competitive structure and raison d'être. They include the plant breeding industry itself, chemicals manufacturing, agro-food manufacturing and individual laboratories specialized in biotechnological R & D. The most important investments in research on plant biotechnologies are increasingly being made by chemical firms, chiefly those engaged in plant protection. It is a highly concentrated industry which has been made even more concentrated by a number of acquisitions, mergers and joint ventures within the industry since the early 1980s. Its high concentration (a small number of firms accounting for large market shares) compared with the plant breeding sector (a large number of firms accounting for small shares of the market) is due to differences in the nature of the products marketed. In the plant protection and agro-chemical industries generally, the same generic chemical can be used in a large number of markets, making it possible to exploit economies of large scale. In contrast, the specificity of different plant varieties to particular soils, climates and other local conditions means that the markets facing plant breeders are segmented and offer little scope for exploiting economies of scale. Moreover, the high cost of creating and developing a new chemical molecule as compared with a new plant variety makes the critical size of a plant protection firm several multiples of that of a plant breeding firm.

24. On the other hand, the lengthiness of the processes involved in creating a plant variety (15 to 20 years are needed before an original programme produces its first results) creates an obstacle to entering the seeds industry. Diversification into that branch is therefore achieved systematically by acquiring plant breeding firms. Since 1970, over 400 seed companies have been bought up, mainly by agro-chemical firms. Despite all of these operations, the plant breeding industry still shows a relatively low level of concentration due to the very great dispersion of capital in the industry and to the fact that, since the beginning of the restructurings, numerous newcomers have decided to withdraw from the branch. These withdrawals reflect the impatience of the newcomers when they see the length of time required for a return on capital, owing to a re-assessment of the requirements of doing business in the industry and to the lag in the application of biotechnologies.

25. Nevertheless, the most important investments in research on plant biotechnologies have been made by the chemical groups, to which the plant protection firms belong, whether or not they are present in the seed market. The three factors that explain this trend are the large size of their assets and turnover, their experience in managing long-term R & D projects and their diversification into other sectors in which biotechnologies may find applications, not merely plant protection or plant pharmacology.

26. More recently, and with more circumspection than the plant protection industry, the agro-food industry has also taken an interest in plant biotechnologies, investing in R & D and in the acquisition of controlling interests in seed companies. In contrast to the plant protection industry, whose investment in plant biotechnologies and seeds is viewed as an activity that complements its original field of interest, the agro-food industry has conceived its diversification towards biotechnology as an activity whose potential applications may assist them in responding to the search for greater diversity and quality in the markets for food in industrialized countries. Conforming to their tendency to avoid in-house research, agro-food companies have, for the most part, sub-contracted their research programmes in biotechnology with enterprises specialized in biotechnological R & D.

27. In terms of size of investment in R & D, specialized biotechnology firms are marginal compared with other sub-branches of the biotechnology industry today. Originally set up by university researchers, mainly in North America, these laboratories were chronologically the first private investors in fundamental biotechnological R & D and were responsible for the integration of biotechnology in the research programmes of the large manufacturing companies. They numbered approximately 20 at the beginning of the 1980s. However, the long research needed before products reach the marketing stage has posed problems of financing. Consequently, most of them have been absorbed by, or are very closely linked to, the larger industrial companies mentioned above. In plant biotechnology today, there remain no more than 10 independent, specialized firms, with annual R & D budgets ranging from $2 to $10 million.

28. In sum, although biotechnology in the developed market economies has not become a substitute for traditional selection techniques used in the seed growing industry, it has brought an increase in the role of the private sector in agricultural research and changes in agro-industry manifested by an increase in R & D budgets, a need for larger firms and greater reliance on R & D co-operation. How these developments will affect the options open to developing countries wishing to benefit from advances in biotechnology may be influenced by the evolution of intellectual property rights protection.

B. Intellectual property rights protection in biotechnology

29. Of the many factors that could play a role in the generation and diffusion of plant biotechnologies, the evolution of intellectual property rights protection can be considered among the most significant. It may be recalled that in most developed countries two systems of protecting intellectual property applicable to plants and plant biotechnological innovations exist: the industrial patent and the plant breeder's right (PBR). Internationally, the two systems are governed by separate conventions, the Paris Convention for the protection of industrial property on the one hand, and the International Convention for the protection of new varieties of plants, on the other. A plant breeder's right is a right granted by Government to plant breeders to exclude others temporarily from producing and selling propagating material of a protected plant variety.

30. For a plant variety to be eligible for PBR protection, it must be distinctive (i.e. clearly distinguishable from other protected varieties), homogeneous or uniform (i.e. its characteristics are uniform) and stable (i.e. its characteristics remain unchanged after repeated reproduction or

propagation). By contrast, industrial patents are granted for inventions which are new (i.e. not previously known), industrially applicable (i.e. serve some specific purpose, have a market, as opposed to existing solely as an idea or concept) and involve an inventive step (i.e. not obvious to a person ordinarily skilled in the art). In addition, inventions must be repeatable, since disclosure under the patent system must enable others to repeat the technical solution described in the patent. Historically, the development of a plant or animal variety has been excluded from patent protection because of doubts as to whether it could be considered an invention satisfying these conditions. For this reason, and in order to provide protection to plant varieties, a separate body of legislation was created based on the PBR.

31. The scope of protection is different under the two systems. First, the rights conferred under the plant varieties' legislation extend only to commercial manufacture and marketing of propagating material at the production stage of the protected variety. Thus, farmers who have bought seeds from a plant breeder (i.e. seed company or any other entity or person producing a new plant variety) are allowed to retain a portion of their crops for resowing the following year without paying again for the use of the seed, whereas patent law would make such a payment mandatory. Secondly, under the breeder's exemption, the utilization of a variety as an initial source of variation for purposes of creating other varieties (even if these possess some of the traits of the protected varieties), or for marketing such varieties, does not require authorization by the breeder of the original variety. This is not the case for patented inventions if they are considered dependent on prior patents.

32. In view of the differences between the two systems of protection, which are mainly due to the differing characteristics of the subject matter of protection, the UPOV Convention obliges member States to provide only one form of protection (patent protection or plant variety protection) for the same botanical genus or species. However, if a State provides for protection by patents, the requirements and effects of such protection must comply with the conditions set forth in the UPOV Convention. Thus, at the time the UPOV Convention was concluded in 1961, and even later, as demonstrated by the Strasbourg Convention on the Unification of Certain Points of Substantive Law on Patents for Invention (1963) and the European Patent Convention (1973), it was widely held that patents for inventions were not a suitable method of protection for plant varieties.

33. As noted in chapter 1, substantial research, inventive effort and investment in biotechnology have produced since then highly sophisticated knowledge of biological processes involving the fundamental components of living plant and animal material. This has made it possible for man to intervene in a systematic way to solve pre-determined technical problems in this field and to describe these processes unambiguously enough to permit experts in the field to carry them out on the basis of the description. As a result of these advances over what could be done with classical selective breeding techniques alone, modern biotechnological process and product innovations have taken on the character of inventions in the similar sense that inventions have been made in applied chemistry and physics.

34. It is in this context that pressures from breeders and industry groups have led to erosion of the principle of non-patentability of living matter and natural processes under the industrial property laws. The United States Supreme Court affirmed the patentability of micro-organisms in 1980. This was

followed by a similar decision on maize in 1985, an oyster in 1987 and a mouse in 1988.[17/] Since 1985, genes, plant parts, plants, plant varieties and processes for developing new varieties and hybrids have all been considered patentable under general patent law in the United States. During the 1980s the drive to patent plant material spread to other industrialized countries, as demonstrated by rulings of the European Patent Office and Japan, although in Europe, the 1973 European Patent Convention explicitly excludes plant varieties and biological processes from patent protection. The appropriate scope of protection of biotechnological inventions and discoveries is currently a matter of debate at the national level as well as in multilateral negotiations. Thus, in 1988, the Directorate-General for Industrial Affairs (DG-III) of the Commission of the European Community submitted a proposal aimed at harmonizing and enlarging patent protection of biotechnological inventions in member States.[18/] Similarly, member States of the International Union for the Protection of New Varities of Plants (UPOV) have for some time been discussing a major revision of the UPOV Convention on PBRs with a view to strengthening protection of plant varieties.[19/] Multilateral negotiations underway within the World Intellectual Property Organization and in the context of the Uruguay Round in GATT have taken up the issue of whether contracting parties should include, inter alia, biotechnological inventions in their patent legislation.

35. The debate on proprietary rights for living material is intense and many legal and even ethical issues remain to be resolved. The move to reinforce patent protection for biotechnological inventions has pitted chemical and biotechnological companies against plant breeders, especially European plant breeders. It has also provoked a North-South debate on property rights to genetic resources.

36. Plant breeders, who generally accept the notion of paying royalties on patent-protected genetic structures used in their varieties, oppose the inclusion, sought by industrialists, of plants and animals per se as patentable subject matter. They argue that PBR legislation is or can be made effective in protecting the interests of holders of patents on genetic structures. Revision of the International Convention for the Protection of New Varieties is seen by breeders as a way of circumventing the extension of patentability to plant varieties by satisfying some of the specific demands of industrialists. Two key features of the draft text for the revised UPOV Convention are the attempts to limit the farmers' privilege and breeders' exemption now assured under existing PBR legislation. The right of the farmer to produce seeds or other propagating material from a protected variety for the purpose of commercial crop growing would be limited in quantity and subject to "adequate" remuneration to the plant breeder. The right of breeders to use a protected plant variety for creating and commercializing a new variety would be proscribed by requiring the authorization of the breeder of the already protected variety in cases where the new variety is genetically related to the protected one. The proposed changes to the UPOV Convention would, if adopted, confer rights on plant breeders similar to those of patent holders.

37. Developing countries, in whose territories is to be found the bulk of in-situ plant genetic resources, have expressed resentment against the notion that laboratory-created products of biotechnology should be the subject of property rights, while the raw materials of the process, which are the fruit of the labour of generations of farmers in their countries, are gathered

freely and without payment. They maintain that the rights of their farmers and plant genetic conservationists should also be recognized. For this purpose, the concept of "farmers' rights" (not to be confused with "farmers' privilege" described above) has been advanced as a counterpart to PBRs and patents. The international recognition of this right would imply a reward to farmers in developing countries for their efforts in producing and maintaining genetic diversity. They would receive payment because they have conserved and improved wild plants and local varieties. However, the concrete legal mechanisms and procedures for translating this idea into practice have yet to be elaborated.

C. Implications for developing countries

38. The foregoing developments in the biotechnology sector -- "privatization" of research, R & D networking, increased industrial concentration and vertical integration, strengthening of intellectual property protection -- have repercussions for competition in the industry for the generation and diffusion of biotechnological innovations and, ultimately for access to technology by developing countries and for their trade and development prospects. The issues are highly complex and an attempt will only be made here to highlight some possible implications for developing countries.

39. The growing relative importance of private as compared with publicly funded agricultural R & D is leading to an extension of the rule of secrecy and confidentiality with regard to the dissemination of knowledge, however positive its effects may be in terms of increasing the level of investment in biotechnology. The growing tendency of even public institutions and universities to patent the results of their research is a further manifestation of the trend towards secrecy which could slow down or make more costly the dissemination of knowledge relevant to developing countries in this field. A similar issue is raised by the change taking place in the way in which agricultural R & D is organized. In so far as they do not participate in the emerging networks of manufacturers, research laboratories and public institutions engaged in the development of biotechnological innovations in industrialized countries, the developing countries are missing out in the generation and sharing of knowledge relevant to their needs and in the negotiation of licences under favourable terms that takes place among the participants.

40. Any assessment of the implications for developing countries of the competitive structure of what has come to constitute the plant biotechnology industry must be made in conjunction with the move towards stronger protection of plant biotechnologies and plant varieties in industrialized countries. Until recently, developing-country research institutions, enterprises and farmers seeking plant biotechnologies and plant varieties in the international market -- including varieties produced through classical breeding techniques -- have been able to consider a range of options in an industry composed of several sub-branches with diverse R & D and marketing strategies. This has been true despite the high seller concentration in the plant protection branch of the industry. However, the drive in industrialized countries to extend intellectual property rights protection to living matter could change this, depending on the form that it takes. One possibility is that patent laws will be extended to cover genetic material (e.g. genes, proteins, plasmids, DNA sequences, tissue, cell lines, etc.) and processes for the manipulation of the material as well as plant and animal varieties resulting from patentable

genetic matter and processes. Under this scenario, both the farmer's privilege and the present free access to protected plant propagating material for the purpose of generating and marketing new varieties will no longer be acknowledged. Alternatively, the industrialized countries could seek to increase protection by extending patent laws only to inventions involving genetic material and processes, while continuing to protect new plant and animal varieties under strengthened PBR laws. The latter would permit the farmer to produce some seed from a protected variety but he would have to pay for the privilege. What is less clear, under the proposed revised draft of the UPOV Convention, is the extent to which the granting of licences to utilize protected varieties to generate new strains will be subject entirely to the discretion of its owner. Under either the patent or PBR scenario, large plant protection firms which have already acquired a substantial inventory of original genetic lines would be able to secure a dominant market position at the expense of more numerous and less powerful seed companies. What this would do to biotechnological innovation in general is not clear. However, the higher returns to companies in the sector could be translated into higher costs to users of the innovations, especially developing countries not linked to the R & D networks and to farmers who could be paying more for seed.

Chapter III

DIRECTION OF RESEARCH AND THE CAPABILITIES OF DEVELOPING COUNTRIES

A. Research pathways in the developed countries

41. As suggested in chapter II, the lion's share of investment in plant biotechnological research is carried out in industrialized countries where the private sector is exerting a growing influence in the determination of research priorities. In view of the high R & D costs, applications of biotechnology would tend to focus on crops and on objectives that could secure large lucrative markets. Two interrelated questions can be raised: (i) are the species and research objectives that are chosen relevant to the crop production or consumption patterns of developing countries? and (ii) what kinds of impacts on developing countries' trade are likely?

42. With respect to choice of species, the answer to the first question is, with some important exceptions, yes. As illustrated in part by table 1, there exists a wide range of commercially attractive species that are either produced and consumed in both developed and developing countries, or are exported by developing to developed countries on a large enough scale to support an R & D effort. Two types of exceptions can be singled out. These are certain crops such as millet, sorghum, teff, cassava, quinoa and several pulses that are grown and consumed mainly in developing countries, are substitutable for imported crops and are of little commercial interest to investors; and beet sugar and a number of oil seeds whose production and consumption in developed countries can (in part because of trade barriers) substitute for imports from developing countries on a scale large enough to attract R & D activity.

43. The myriad research objectives pursued in plant biotechnology may be divided into four categories:

(a) To increase the potential yield by improving the genetic potential of varieties;

(b) To optimize the attainment of potential yield by eliminating cultivation stresses;

(c) To adapt more fully to industrial uses; and,

(d) to improve crop quality.

44. For the most part, industrialized countries tend to pursue the first, second and third objectives; whereas developing countries tend to concentrate on the second and fourth. Moreover, the way in which the objectives are pursued also differs as between developed and developing countries. The reason for both of these differences for a given set of crops stems from the contrast in geographic and climatological conditions, the degree of technical progress already achieved in the selection of varieties suitable to those conditions, and the relative importance of private industrial firms engaged in R & D in this field.

45. Thus, the more temperate climate in developed countries has meant that research directed towards optimizing the attainment of potential yield has focused on the control of different pathogens and pests for given crops than

those focused on in developing countries. Moreover, until recently, the plant protection branch of the chemicals industries in developed countries has directed much of its research efforts towards developing herbicide-resistant varieties, in order to extend the economic life of its herbicides.20/ Such an emphasis is obviously of less relevance to less industrialized countries whose chemical industries are far less advanced and whose major attention is addressed directly to diseases. Owing to the interest of their food processors, much of the R & D effort in developed countries is also devoted to adaptation or diversification of crops for industrial processing, as illustrated by the work done to produce varieties of tomato with a greater content of dry matter for the production of concentrate and varieties with greater shelf life. Since agriculture in developed countries has already realized considerable progress in optimizing the attainment of actual potential yields, firms engaged in plant biotechnological research in those countries are directing their efforts in the longer term towards the improvement of potential yields -- through, for example, the improvement of photosynthetic capacity and the discovery of nitrogen-fixing genes. Research into male sterility of plants is one of the major pathways in pursuit of a double objective: increased yield and technical protection of innovations through the generation of hybrids. Seeds from hybrids, it may be recalled, cannot be effectively re-sown after the first or second planting, thereby diminishing the need for intellectual property rights protection. Technical obstacles to the creation of hybrid varieties of wheat as compared with maize explain the greater past investment in R & D on maize than on wheat varieties despite the greater commercial importance of wheat globally.

46. The possible impact described in table 1 of biotechnological innovations on developing countries' trade in agricultural crops of plant origin by the year 2000 is potentially large. However, taken by itself, the direction of R & D conducted in developed countries by the private sector would suggest that the realized positive net impact on developing countries' trade in agricultural plant products (through more competitive exports, less costly imports or increased competitiveness of domestic substitutes) could be small. Positive effects would be most likely to occur from the R & D efforts to increase yields conducted by developed-country enterprises that are importers of tropical products. In other respects, the projected effects are mixed. Research on cereals and other large-scale crops that can be grown both in developed and developing countries could economize foreign exchange for those countries that are net importers, but could only benefit domestic producers of such crops if the research were adapted to local conditions. Production in developing countries of crops such as millet, sorghum, cassava and certain pulses grown almost exclusively for domestic consumption and not of commercial interest to large companies could, however, be adversely affected by innovations in large-scale cereal crops with which they compete. Biotechnological R & D in the developed countries could also produce adverse effects on exports of some developing countries. Such could be the case for cane sugar that would be hurt by improvements affecting sugar-beet production and (with the reservations expressed in chapter I) a few tropical product exports that could in the long term be injured by the application of tissue culture techniques to the direct production of plant substances replacing, for instance, spices and medicinal plants.

B. The status of research in and for developing countries

47. Available evidence on the state of plant biotechnology in developing countries is fragmentary and piecemeal. Nevertheless, it permits a certain number of observations to be made.

48. The number of countries that can be expected to be able to use recombinant DNA techniques to manipulate genetic material for crop improvement is small -- probably less than ten.[21/] These countries have the alternative of either working at the frontiers of knowledge in developing major improvements on selected indigenous varieties of commercialized or commercializable crops or adopting a more imitative strategy directed towards achieving less dramatic but quicker and surer returns based on the adaptation and application of the more routine biotechnological techniques; or of some combination of the two approaches. The great majority of developing countries can be divided into sub-groups: those that have the R & D capacity to adapt biotechnology to their local conditions following the second of the above strategies; and those -- mainly among the least developed countries -- that do not.

49. The generation and transfer of biotechnologies from developed to developing countries, without a substantial involvement of local R & D personnel, face an uncertain prospect of success owing to unduly high R & D costs relative to the size of the market, specific conditions of cultivation and unrealistic assumptions about adaptability. This applies especially to crops destined for the domestic market. An example of the problem of adaptation is the case of maize varieties exhibiting high methionine rates and developed in the industrialized countries for animal feed and, more specifically, poultry feed. Scientists have envisaged being able to substitute this species for the haricot bean, which is deficient in amino acids and which forms the staple food in several developing countries. The idea has come up against established habits of production and of consumption -- problems that could be foreseen and resolved or circumvented if local R & D personnel with first-hand knowledge of their countries' agriculture played a more prominent role in the research process.

50. This is not to suggest that there do not exist plant biotechnologies developed or likely to be developed in industrialized countries that can be transferred to developing countries without the mediation of local R & D laboratories and institutes. The most outstanding example is diagnostic tests mentioned in chapter I. Diagnostic tests based on monoclonal or polyclonal antibodies constitute a particularly effective tool for the detection of diseases (in particular, virus attacks) in plants, but also in soils or in carrying out plant selection programmes. Diagnostic kits are becoming a standardized technology whose use at the farm level requires no special knowledge, and whose potential contribution to agricultural productivity and, by extension, to exports of developing countries could be significant.

51. For developing countries having at least a nucleus of qualified researchers in plant biotechnology, few technologies present greater potential in terms of adaptability to needs and ease of adaptation than the collection of techniques known as tissue culture. They have many applications today: for the development of new strains, for research into cultivars with a higher yield potential, or to speed up programmes of varietal creation through quick multiplication of a large number of selected individual plants having a desired set of characteristics. The low investment cost and ease of use of these techniques make them especially attractive.[22/] Although genetically-engineered plants are unlikely to be created in most developing countries for quite some time, once the desirable genes have been identified and transgenic plants created in a developed country for a given crop variety, developing countries with a capacity in tissue culture could use genetically

engineered cells from these plants to create and reproduce whole new varieties of the same crop or of another crop suitable to their own conditions of cultivation.

52. Modern plant biotechnology is not a panacea. The ability to adopt and fully benefit from this set of techniques is predicated not only on the adequacy of human resources and institutional infrastructure in this field but also on the existence of an adequate programme of conventional agricultural research, including especially the selection and propagation of new plant and seed varieties. The Food and Agriculture Organization has for several years surveyed the state of development of the seeds sector, country by country. The results of the latest survey are shown in table 3. For the African continent the results are highly unsatisfactory, for in fewer than one in four countries are there correctly developed programmes for the improvement of food plants; fewer than one country in ten is conducting research on all types of crops -- industrial, vegetable and pasture crops. With respect to production and monitoring of seeds, the situation is scarcely better. The American region has decidedly better-developed infrastructures, while Asia is somewhere between the two.

53. From the point of view of the size of commitment of financial resources, research in plant biotechnology organized by or for developing countries can be considered marginal. Owing to the size of their markets, the very large number of species involved and the wide variety of cropping conditions, the specific needs of developing countries are difficult to access. Nevertheless, there exist a certain number of initiatives that are advancing significantly the state of knowledge on species of direct interest to developing countries. The multilaterally-funded international agricultural research centres (IARCs) which exercized an instrumental role in the Green Revolution have begun to allocate resources to investment in biotechnology through, inter alia, the establishment of centres of excellence and international scientific exchange networks for tropically-grown crops, as illustrated by some of the work on rice and cassava research described below.[23/]

54. Since rice is not a leading food source for the developed countries, there has been relatively little private-sector interest in rice compared with the other major cereals. This gap is now beginning to be filled through publicly-funded efforts. The International Rice Research Institute (IRRI), with a staff of 120 scientists and an annual budget of $33 million, has recently defined a new research strategy in which biotechnology constitutes an essential element. Several innovations are in the process of development, including hybrids with 15 per cent improvement in yields, disease-resistant varieties and insect-resistant varieties. The international effort on rice is co-ordinated and largely financed by the Rockefeller Foundation which supports research at 25 and 34 institutions in developed and developing countries, respectively, as well as in two International Agricultural Research Centres. Progress has been significant: tissue culture techniques have contributed to productivity gains, RFLP mapping of rice has advanced and genetic engineering has proven feasible.

55. International cassava research is being co-ordinated by the Centro Internacional para Agricultura (CIAT) in Colombia, while the International Institute for Tropical Agriculture (IITA) has regional responsibility for Africa. CIAT's research targets, which were established through consensus

Table 3

The state of the seeds industry in the developing countries and China

Region [a] *and crop group*	*Variety improvement*			*Seed quality control*			*Seed production & distribution*		
	A %	B %	C %	A %	B %	C %	A %	B %	C %
Africa (37)									
Crop group:									
food	22	72	6	28	61	11	28	72	0
industrial	8	56	36	20	22	58	11	58	64
vegetable	0	39	61	5	28	67	0	36	64
pasture	3	14	83	8	8	84	3	14	83
America (25)									
Crop group:									
food	80	8	12	60	24	16	56	24	20
industrial	50	16	32	60	24	16	44	12	44
vegetable	16	32	52	12	16	72	0	44	58
pasture	16	24	60	28	12	60	8	32	60
Asia [b] (30)									
Crop group:									
food	59	31	10	47	33	20	41	48	11
industrial	35	10	55	23	23	54	28	11	61
vegetable	24	35	41	27	23	54	21	21	58
pasture	14	14	72	13	10	77	14	7	79

Source: *FAO Seed Review, 1984-85*, Food and Agriculture Organization of the United Nations, Rome, 1987.

a The figures in parentheses indicate the number of countries in the region.
b Includes China.

A = well developed
B = fragmentary or pilot scale operation
C = no activity reported

among Latin American and African scientists, are: development of true-seed propagated cassava, elimination of toxic compounds, development of varieties resistant to mosaic virus and development of transformation and regeneration systems for transgenic plants. To achieve these targets, CIAT established the Advanced Research Network on Cassava (ARNC) in 1988, whose programme will be modelled on the Rockefeller Foundation's International Rice Biotechnology Programme. It has begun to seek funds from bilateral and international agencies. Other international collaborative efforts include joint research between CIAT, the International Potato Research Center (CIP) and Louisiana State University aiming at introducing the potato's gene for protein storage into cassava; and the International Cassava-Trans project carried out by the French developing-country research agency, ORSTOM, and Washington University in St. Louis, in the United States, aimed at cloning of genes and transformation, regeneration and evaluation of potato plant varieties.

56. The importance of cacao for both the food and the speciality chemicals industry makes it one of the crops targeted by developed market-economy country research efforts. The main lines of research include: clonal propagation of high-yielding, disease-resistant plants, genetic engineering to raise the fat content of the beans and, as noted in chapter I, the use of tissue culture techniques for the production of cocoa butter. The single most important research programme aiming at the clonal propagation of high-yield plants is probably that of Pennsylvania State University in the United States, supported by the American Cocoa Research Institute and the Chocolate Manufacturers' Association of the United States. Similar research is also pursued in other industrialized countries. Moreover, several exporting countries, such as the Côte d'Ivoire, Ghana and Costa Rica, are also undertaking research on cacao plant improvement. Hence, it would appear that the development of high-yielding varieties will be among the first applications of biotechnology to cacao.

57. The work on rice, cassava and cacao is laudable. However, a vastly larger effort will be required of developing countries and the international community on these and other crops before biotechnology can be expected to come even close to achieving its potential in raising the productivity of agriculture in developing countries.

Notes

1/ Proposed by the World Bank advisors in G. Persley, ed. Agricultural Biotechnology, Opportunities for International Development - Synthesis Report, World Bank, Australian International Development Assistance Bureau, The Hague, May 1989.

2/ According to an OECD report "...in agriculture, the biotechnological tools liable to have an impact on production and trade draw on a wider range of techniques than genetic engineering ...", several of which were developed in the 1970s and "... have had time to develop identifiable impacts", Biotechnology: Economic and Wider Impacts, OECD, Paris, 1989.

3/ A company in the United States stated that it was able to produce new soybean varieties 20 to 40 per cent faster through tissue culture methods than with ordinary breeding. Agricultural Biotechnology News, vol. 2, No. 1, 1986.

4/ The microbe in this process acts only as an intermediary. Since the gene in question is multiplied in virtually unlimited quantities as the gene-carrying microbe multiplies, it becomes available for subsequent transfers to cells of other plants after the initial transfer is completed.

5/ The acronym RFLP stands for restriction fragment polymorphism mapping.

6/ The botanical term is dicotyledons.

7/ The botanical term is monocotyledons, which also include bulbs, orchids, palms, bananas, plantains and yams.

8/ Unilever's first attempt to cultivate its 40 clones of high-yielding oilpalm varieties in Malaysia was frustrated by flowering abnormalities, though efforts have continued with another set of clones. L. Jones, "Perennial tropical oil crop improvement and biotechnology" cited in G. Persley ed., Agricultural biotechnology, opportunities for international development: synthesis report. World Bank, Australian Center for International Agricultural Research, Australian International Development Assistance Bureau, The Hague, 4 May 1989.

9/ At present, plant-tissue culture techniques provide a viable alternative only for substances valued above several hundred dollars per kilogram according to A. Sasson, Biotechnology and development, United Nations Educational Social and Cultural Organization, Paris, 1988. Predictions of several years ago that the chocolate industry might some day produce cocoa butter in culture that would compete with the same product extracted from cacao is no longer given credibility because of insurmountable technical problems that have since been encountered and the prohibitive cost - $200 per ton - even if the problems were overcome. R. Walgate, Miracle or menace? Biotechnology and the Third World, Panos Institute, London, 1990.

10/ Although its DNA has been more extensively mapped than that of any other plant species, researchers have located and identified the functions of only 250 of the tomato plant's genes. E. Lachkovics, "Journey to the centre of life: introduction to the new biotechnologies", in Development dialogue, Dag Hammarskjold Foundation, Uppsala, 1988: 1-2.

11/For example, it has been ascertained that more than 17 genes coding for the enzymes involved in nitrogen fixation have been identified in the Rhizolim bacterium found in the nodules of leguminous plants. "To the complexity of transferring these 17 genes to non-leguminous plants must be added that of transferring the genes necessary for the formation of the Rhizobium nodules themselves". M. Greeley and J. Farrington, "Potential implications of agricultural biotechnology for the Third World" in J. Farrington, ed., Agricultural biotechnology: prospects for the Third World, Overseas Development Institute, London, 1989.

12/Shikonin used as a dye, ointment and cosmetic, and normally extracted from the root of a plant produced in China, Japan and the Republic of Korea, is the only one of these products reportedly being synthesized in culture and sold in the world market. Two other synthesized products reported to be close to commercialized production are pyrethrin, an insecticide normally extracted from the pyrethrum flower grown in Kenya, Tanzania and Ecuador and digtoxindigoxin (from digitalis) a pharamceutical used in the treatment of Parkinson's disease. M. Kenney, F.H. Buttel and J. Kloppenburg, Jr. "Import of industrial applications" in "Tissue culture technology and development", ATAS Bulletin, November 1984.

13/Even if the problems could be resolved, the already existing cost advantage of the agriculturally grown crop risks being widened by the competing research in selecting and propagating improved varieties of the whole plant. Such research is in full swing on cacao, vanilla and pyrethrum.

14/The fact that some products are cultivated and exported by both developed and developing countries, uncertainties about the pace with which new or improved varieties will be adopted and diffused in different parts of the world once they are developed, substitution effects of various kinds between different commodities (e.g. beet vs. cane sugar or palm vs. groundnut oil), economic factors such as commodity prices, agricultural and trade policies and regulatory regimes, are but a few of the variables that would have to be considered in estimating such an impact.

15/This estimate is from P.B. Joly and C. Ducos, "Les facteurs de la genèse et de la diffusion des biotechnologies végétales: menaces et opportunités pour les pays en voie de développement" - report prepared for the UNCTAD secretariat, August 1990.

16/The numerical estimates in this paragraph are from P.B. Joly and C. Ducos, op.cit., August 1990.

17/The four decisions are, respectively: United States Supreme Court decision of June 16, 1980, Diamond v. Chakrabarty, 206 USPQ 193 (1980); Ex parte Hibberd, involving a patent for a plant 227 USPQ 443 (PTO Board of Patent Appeals and Interferences, 1985); Ex parte Allen, deciding that an oyster could be patentable subject matter 2 USPQ 2d 1425 (PTO Board of Patent Appeals and Interferences, 1987); and United States Patent 7 735 866, issued to the President and Fellows of Harvard College on April 12, 1988.

18/Commission of the European Communities (1988), "Proposal for a Council directive on the legal protection of biotechnological inventions", COM(88)496 final, SYN 159, Brussels.

19/ International Union for the Protection of New Varieties of Plants, "Revision of the Convention: Draft Substantive Law Provisions" (IOM/5/2 Rev.), August 22, 1990.

20/ The re-emergence of concern over the environment is expected to lead to some re-direction of future R & D towards biological and other mechanisms of weed control.

21/ R. Barker, "The impact of modern biotechnology on developing countries: some emerging issues", Working papers in agricultural economics, Cornell University, Ithaca, New York, December 1989.

22/ The problems currently encountered in the application of plant tissue and cell culture techniques have been discussed in chapter I.

23/ In addition, the International Centre for Genetic Engineering and Biotechnology, recently organized by the United Nations Industrial Development Organization, carries out research and training in molecular and cell biology of which one of the major areas of emphasis is the application of genetic engineering techniques to the improvement of crops that are important to developing countries. The World Bank's investment in agricultural research includes support for plant biotechnology components in its country projects and through its annual grants to the IARCs.

Annex table I

A. Developing-country/territory exporters of the selected agricultural commodities depicted in table I

(Average 1985-1987)

Commodity	*Developing-country/territory exporters* [a] *(percentage share of individual commodities in exporter's total trade)*
Cereals	
Wheat	Argentina (8.8), Guadeloupe (7.5), St. Vincent (9.4)
Rice	Myanmar (25.9), Suriname (12.2), Pakistan (9.2), Thailand (8.0), Uruguay (6.9), Guyana (6.2)
Maize	Argentina (8.0)
Sorghum	Sudan (7.6)
Vegetables	
Cassava	Thailand (6.4)
Potatoes	Cyprus (6.4)
Fruits	
Bananas	St. Lucia (63.1), Dominica (62.0), Guadeloupe (48.2), Martinique (48.0), St. Vincent (30.9), Honduras (30), Panama (24.3), Costa Rica (20.8), Somalia (15.7), Tonga (14.6), Cape Verde (14.5), Grenada (12.8), Ecuador (10.3), Guatemala (7.1), Nicaragua (5.9), Belize (5.3)
Sugar	
Sugar	Cuba (74.5), Reunion (73.7), Fiji (42.8), Mauritius (39.2), Swaziland (35.8), Guyana (35.0), St. Kitts (34.9), Belize (30.0), Dominican Rep. (20.5), Guadeloupe (12.0), Barbados (10.3), Jamaica (9.9), Malawi (9.8), Mozambique (7.1), Panama (6.7), Guatemala (5.1)
Tropical beverages	
Coffee	Uganda (88.2), Burundi (82.9), Rwanda (75.9), Ethiopia (66.4), El Salvador (65.8), Colombia (47.9), Nicaragua (46.3), Guatemala (42.7), Tanzania United Rep. (38.9), Madagascar (36.9), Costa Rica (32.6), Kenya (31.6), Honduras (24.0), Zaïre (22.1), Cameroon (22.0), Haïti (21.4), Côte d'Ivoire (19.7), Central African Rep. (18.6), Yemen (18.1), Papua New Guinea (14.8), Dominican Rep. (12.6), Sierra Leone (12.2), Togo (11.6), Lao People's Dem. Rep. (11.5), Brazil (9.3), Ecuador (11.0), Peru (6.8), Equatorial Guinea (5.1)

Annex table I (contd.)

A. Developing-country/territory exporters of the selected agricultural commodities depicted in table I

(Average 1985-1987)

Commodity	*Developing-country/territory exporters* [a] *(percentage share of individual commodities in exporter's total trade)*
Cocoa	Ghana (55.1), Sao Tome & Principe (55.0), Equatorial Guinea (38.4), Côte d'Ivoire (36.3), Cameroon (17.0), Grenada (14.4), Benin (14.3), Sierra Leone (12.4), Samoa (9.6), Dominican Rep. (9.2), Togo (8.8), Vanuatu (7.2), Ecuador (6.7), Solomon Islands (5.9), Papua New Guinea ((5.7)
Tea	Sri Lanka (30.1), Kenya (22.1), Malawi (15.2), Rwanda (9.2), India (5.2)
Spices	
Vanilla	Comoros (61.7), Madagascar (19.8)
Oilseeds & oleaginous fruits	
Soyabeans	Paraguay (27.7) Argentina (17.2) Brazil (8.4)
(Soyabean oil)	[b]
Sunflower seeds	Argentina (7.2)
(Sunflower oil)	[b]
Coconuts (copra)	Kiribati (56.0), Samoa (43.4), Tonga (37.8), Pacific Islands (20.2), Solomon Islands (12.2), Philippines (9.6), Sao Tome & Principe (8.4) French Polynesia (5.7), Sri Lanka (5.6)
(Coconut oil)	Samoa (37.3), Tonga (26.0), Pacific Islands (9.4), Philippines (7.0) French Polynesia (5.7)
Oil palm	Malaysia (10.1), Solomon Is. (8.3), Guinea Bissau (6.7)
(Palm oil)	Malaysia (9.7), Solomon Islands (7.9)
Raw materials	
Tobacco	Malawi (52.8), Zimbabwe (20.4)
Rubber	Cambodia (87.7), Liberia (20.9), Malaysia (8.3), Sri Lanka (7.7), Thailand (6.4)
Cotton	Burkina Faso (40.3), Sudan (38.3), Mali (36.5), Paraguay (28.1), Nicaragua (23.7), Benin (23.3), Chad (20.6), Pakistan (13.3), Togo (13.1), Egypt (10.5), Tanzania United Rep. (9.9), Central African Rep. (9.1), Syrian Arab Rep. (8.0), Zimbabwe (6.9), Mozambique (5.0)

Annex table 1 (contd)

B. Developing-country/territory importers of the selected cereal commodities depicted in table 1

(Average 1985-1987)

Commodity	*Developing-country/territory importers* [c] *(percentage share of individual commodities in importer's total trade)*
Wheat & flour	Sudan (13.3), Ethiopia (12.7), Egypt (10.0), Bangladesh (8.7), Bolivia (7.7), Mauritania (7.0), Somalia (7.0), Haïti (6.8), Algeria (6.4), Morocco (5.7), St. Vincent (5.0), Peru (4.9), Sao Tome & Principe (4.5), Sri Lanka (4.4), Lao People's Dem. Rep. (4.1), Iraq (3.8), Iran (3.7), Mozambique (3.6), Kiribati (3.6), Dominica (3.4), Zaïre (3.4), Sierra Leone (3.4), Syrian Arab Rep. (3.3), Tunisia (3.3), Afghanistan (3.2), Gambia (3.2), Pakistan (3.2), Tuvalu (3.2), Ecuador (3.1), Tonga (3.1), Maldives (2.8), Cuba (2.8), Brazil (2.7), Jamaica (2.6), Yemen (2.6), Fiji (2.5), Jordan (2.5)
Rice	Guinea Bissau (17.4), Sierra Leone (15.2), Cambodia (14.5), Liberia (12.7), Gambia (10.2), Comoros (9.6), Madagascar (9.4), Sao Tome & Principe (7.2), Lao People's Dem. Rep. (7.1), Mauritania (7.1), Senegal (6.3), Kiribati (5.9), Pacific Islands (5.5), Somalia (5.2), Mali (4.6), Guinea (4.3), Côte d'Ivoire (4.2), Mozambique (4.1), Vanuatu (4.0), Solomon Islands (3.3), Cape Verde (3.3), Niger (3.3), Equatorial Guinea (3.2), Bangladesh (3.0), Maldives (2.9)

Source: As in table 1.

a Countries for which the share of exports of the commodity in question in total exports is above 5 per cent.
b There is no country for which the commodity accounts for 5 per cent of total exports.
c Countries for which share of imports of the commodity in question in total imports is 2.5 per cent and above.

Annex table II

Commodity coverage of tables 1, 2 and annex table I

Commodity	*SITC (Revision 2)*
Wheat	Wheat (FAO Trade Yearbook tapes) +046
Rice	042
Maize	044
Barley	043
Sorghum	045.92
Millet	045.91
Triticale	045.99 (part of)
Rye	045.91
Cassava	Fresh and dried - FAO Trade Yearbook tapes
Yams	FAO Trade Yearbook tapes
Sweet potatoes	FAO Trade Yearbook tapes
Potatoes	054.1
Tomatoes	054.4
Bananas/plantains	057.3
Pineapples	057.95 + 058.9
Sugar	061.1 + 061.2
Coffee	071.1 + 071.2
Cocoa	072
Tea	074.1
Vanilla	075.21
Soyabeans	081.31 + 222.2 + 423.2
Sunflower seeds	081.35 + 222.4 + 423.6
Rapeseed	081.36 + 222.6 + 423.91
Coconuts (copra)	057.71 + 081.37 + 223.1 + 424.3
Oil palm	081.38 + 223.2 + 424.2 + 424.4
Tobacco	121
Rubber	232 - other natural gums (FAO Trade Yearbook tapes)
Cotton	263